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DEVELOPMENT OF LASER WELDING TECHNIQUES FOR JOINING ARMOR.(U)

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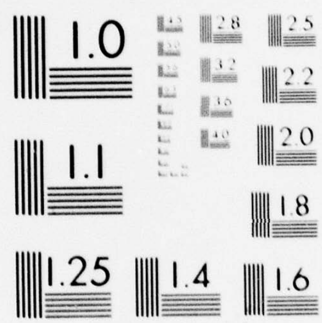

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(Report No. IITRI-B6157-Q1)
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6 DEVELOPMENT OF LASER WELDING TECHNIQUES
FOR JOINING ARMOR

AD A072536

Department of the Army
US Tank - Automotive Research
and Development Command
Warren, MI 48090

11 31 Dec 78

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TABLE OF CONTENTS

FIGURES

TABLE

DEVELOPMENT OF LASER WELDING TECHNIQUES
FOR JOINING ARMOR

1. INTRODUCTION

The multikilowatt laser as an industrial tool in the production line has now been accepted for over three years. Recently, the laboratory feasibility of heavy penetration laser welding was demonstrated in low strength steel by the IITRI Laser Center (Fig. 1). recently

The objective of this program is the establishment of laser welding process parameters that will produce a sound, cost-effective joint with ballistic potential in 1-1/2 in. armor plate. Sufficient production, test, and operational data will be prepared to permit a detailed analysis of the achievement of this objective and repeatability of the process. Ballistic testing is not within the scope of this initial work.

The program material is MIL-A-12560C(MR)(Mn-Mo) 1-1/2 in. armor plate. The program welding electrode is MIL-E-19822. A 20° V-joint (Fig. 1) will serve as the initial configuration for laser filler wire welding. Work will be accomplished with a 10.6 micron beam from a 15 kW CO_2 laser.

(20 deg

An overview of the proposed program is shown in Fig. 2.

2. EQUIPMENT

The program will be conducted at the IITRI Laser Center 15 kW CO_2 laser facility. The Laser Center employs a CO_2 (CW) beam and associated optics to provide a maximum of flexibility for development studies from 1 to 15 kW (Fig. 3). Characteristics of the facility are summarized in Appendix 1. The CO_2 CW laser source, and the coherent 10.6 micron (far infrared) light produced, form the heart of the system. The power level is accurately maintained by a closed loop control, utilizing a technique

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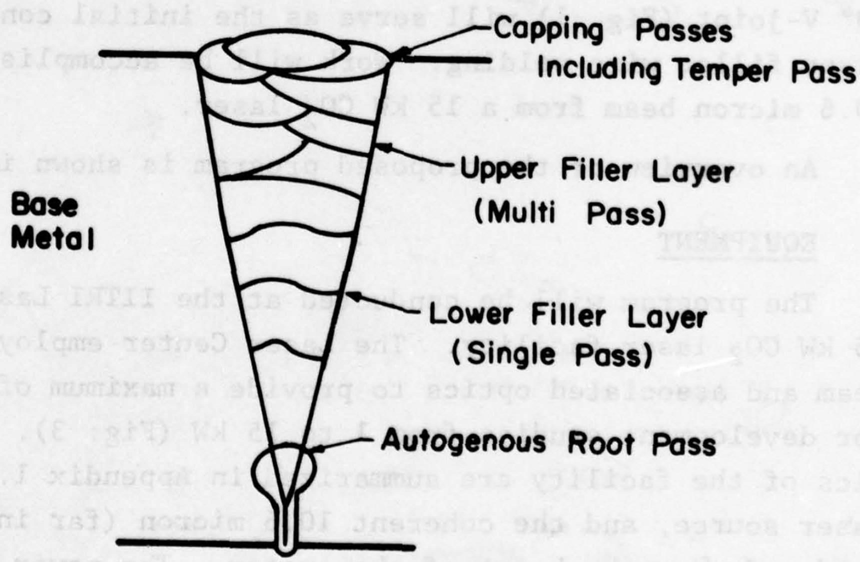
(a) Commercial weld in AISI low carbon steel



(b) Schematic elements of a narrow gap weld

Figure 1 Initial IITRI Weld Trials

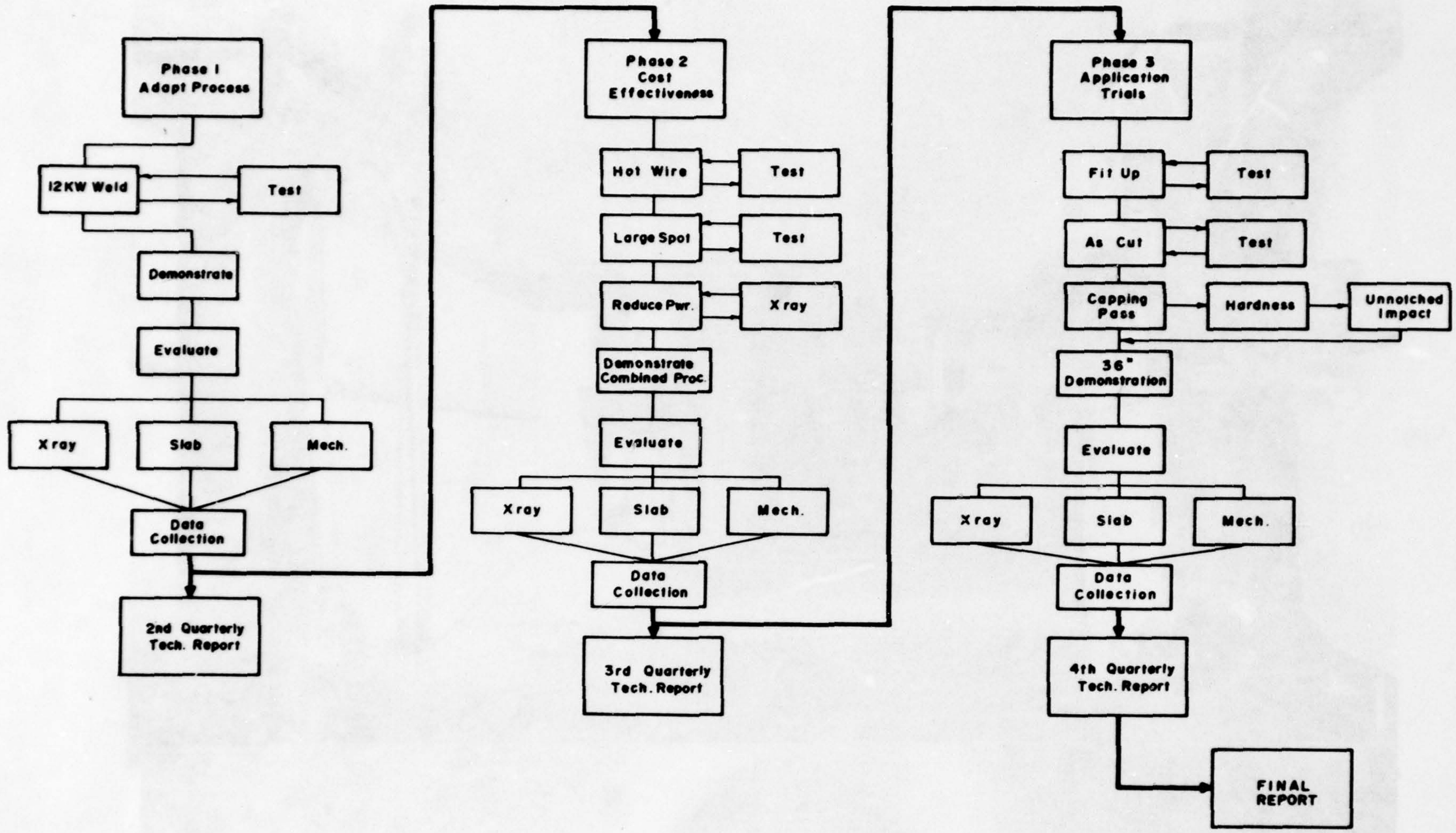


Figure 2 Work Flow in IITRI Program

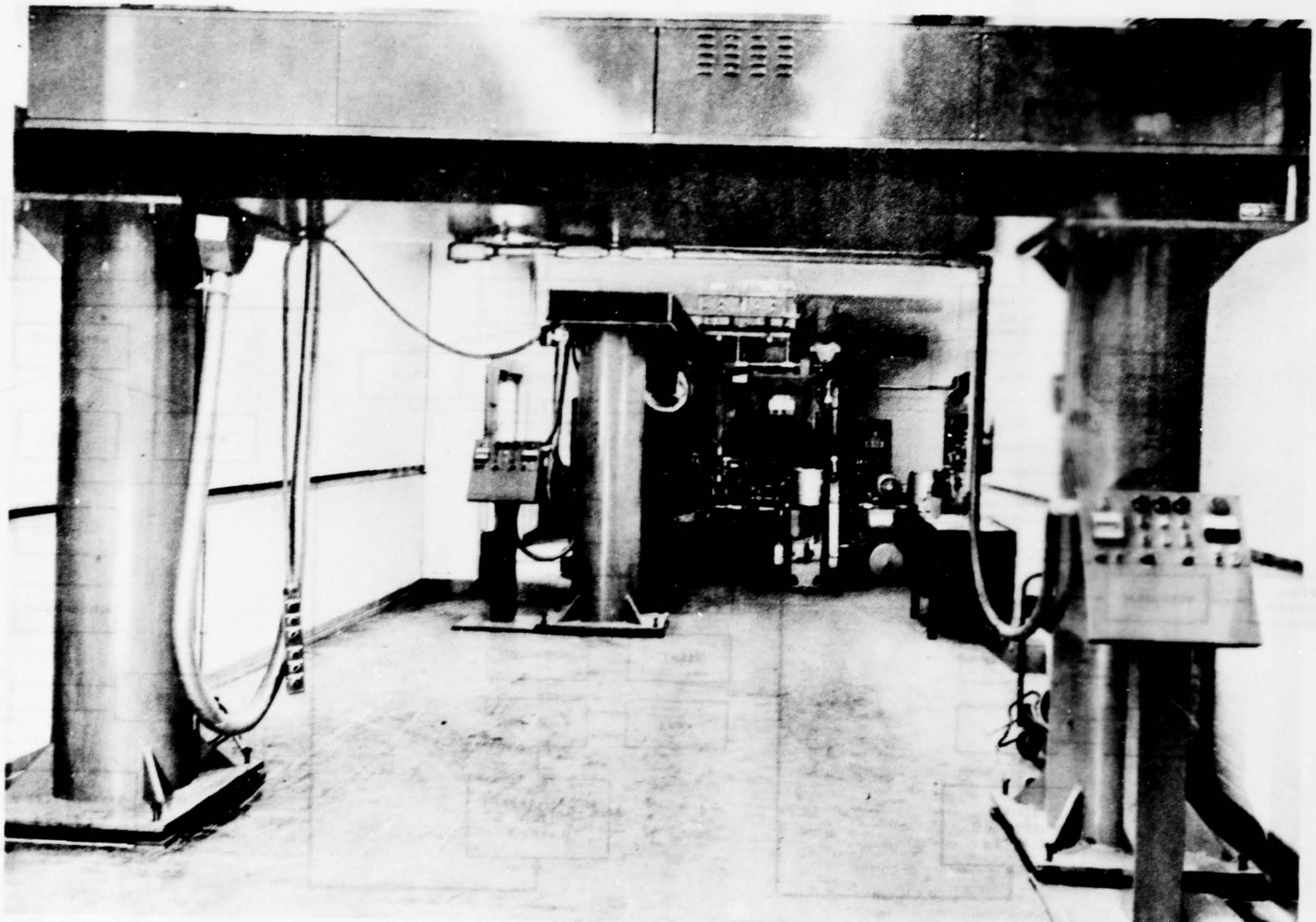


Figure 3 Two Station Laser Facility

called electron beam stabilization. Experiments are conducted from consolettes at either of the two available work stations (Fig. 3). The consolettes contain all the functions necessary for sequencing, monitoring, and controlling the system. From these consolettes the entire system can be operated automatically by time sequence control or manually as desired by the experimenter. Additionally, the system is compatible with external numerical or computer control.

To provide a full range of experimental capabilities and a high level of efficiency the system includes two work stations; one is for heat treating (nearest the camera in Fig. 3), and the other produces a sharply focused beam. The latter capability will be used for this welding program, and the equipment is shown in Fig. 4. The work is moved under the beam by the modified machine tool, and the wire feed is fixed with respect to the beam. The height and the transverse position of the beam in the joint can be adjusted ±0.005 in. for experimental reproducibility, not because the process necessarily requires it.

3. PROGRESS

The program is on schedule. The progress for the reporting period is described in the following paragraphs.

3.1 Task 1 - Procurement of Armor Plate

Three plates of 1 1/2 in. thickness, weighing a total of approximately 3575 lb, were purchased from a recognized supplier of MIL-A-12560C (MR). Emphasis was placed on availability to maintain program schedule. Certification of the material has been obtained and is attached as Appendix 2. The composition of the material is as follows:

C	Mn	P	S	Si	Mo	Al	B
0.26	1.43	0.008	0.010	0.25	0.50	0.043	0.003

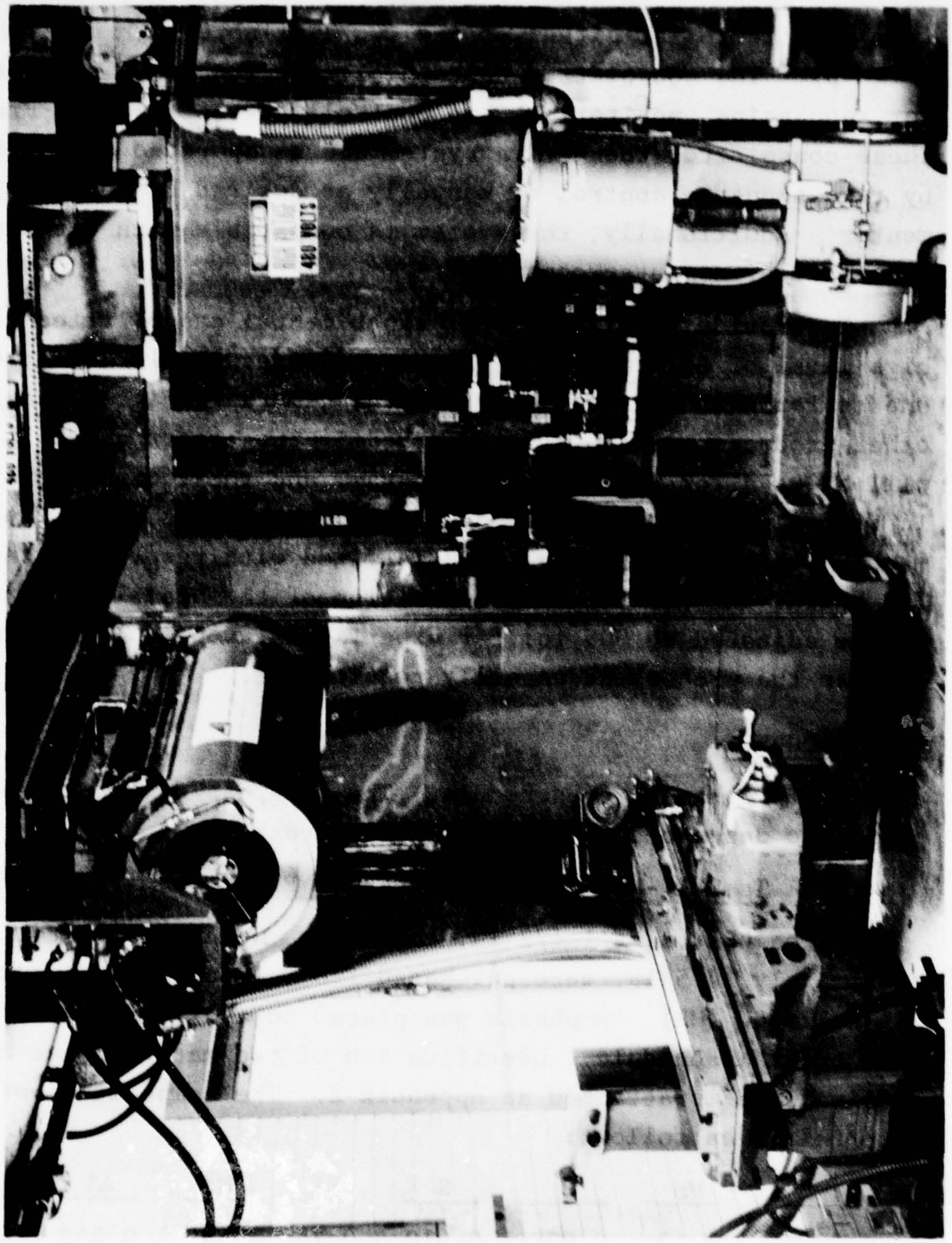


Figure 4 Laser Welding Station

The hardness of the plates are reported by the mill as:

	No. 1 End	No. 2 End
Top Surface	321 BHN	302 BHN
Bottom Surface	302 BHN	302 BHN

The plates come from a lot that has been qualified ballistically.

3.2 Task 2 - Procurement of Welding Wire

Initial procurement involved three 35 lb reels of 0.062 in. wire to MIL-E-19822A (Ships), dated 15 August 1961, and represents the commercial description AIRCO A632. Other 35 lb reels will be procured as required throughout the program. The nominal composition of A632 is:

C	Mn	P	S	Si	Ni	Mo	V
0.08 Max.	1.15/ 1.55	0.025 Max.	0.025 Max.	0.35/ 0.65	1.15/ 1.55	0.3/ 0.6	0.1/ 0.2

The vendor reports the following for the specific heat of wire involved in these tests:

C	Mn	P	S	Si	Ni	Cr	Mo	V
0.063	1.37	0.005	0.017	0.55	1.31	0.10	0.40	0.12

Ultimate:	122,800 psi
Yield:	110,000 psi
Elong.:	18% (in 2 in.)
Charpy (-60°F):	30,29,31,24,23 ft-lb

3.3 Task 3 - Prepare Test Specimens

The plates have been delivered to the flame cutting facility where they are being cut into 4 in. wide strips. The cut for the single Vee configuration will be at 10° to form the final 20° V by inverting one side. The strips will be flame-cut to 12 in. and 36 in. segments (approximately 108 of the former and 36 of

the latter). Twelve of the shorter segments and all 36 in. segments will be left as cut, except for root face preparation. The root face will be applied by machining (see Fig. 5).

A preliminary set of specimens has been obtained from an available piece of plate and prepared by machining. In the following Task 4 discussion, it is these machined specimens that are involved. Additionally, in these early tests a supplementary reel of A632 wire was employed. The analysis of this wire will be reported in the next period.

3.4 Task 4 - Adaptation of a Procedure to Armor

The industrial 12 kW wirefeed process was applied to a series of nine joints. Visual observation were made on a pass-by-pass basis and appropriate corrective action taken. Two locations were marked for the removal of a cross-section slice.

Figure 6 shows the specimen hold-down tooling. Several tons of clamping pressure can be exerted and, after each weld, the specimen is checked to determine if at any time it slipped and relaxed the restraint on the specimen.

Figure 7 shows the wire feeder.

A set of test specimens shown in Fig. 8, and Fig. 9 shows the setup of a root pass on the specimens. Figure 10 is a close-up of the wire feed and off-axis gas nozzles arrangement employed in these tests. One side of the specimen has been removed for clarity. Figure 11 shows a hood substituted for the nozzles. The hood appears easier to position and nearly eliminates the oxidation that occurs as the metal in each pass cools.

Welding

Table 1 describes the welding procedure variations that were explored during this period. All welds in the series could be described in the following general procedure:

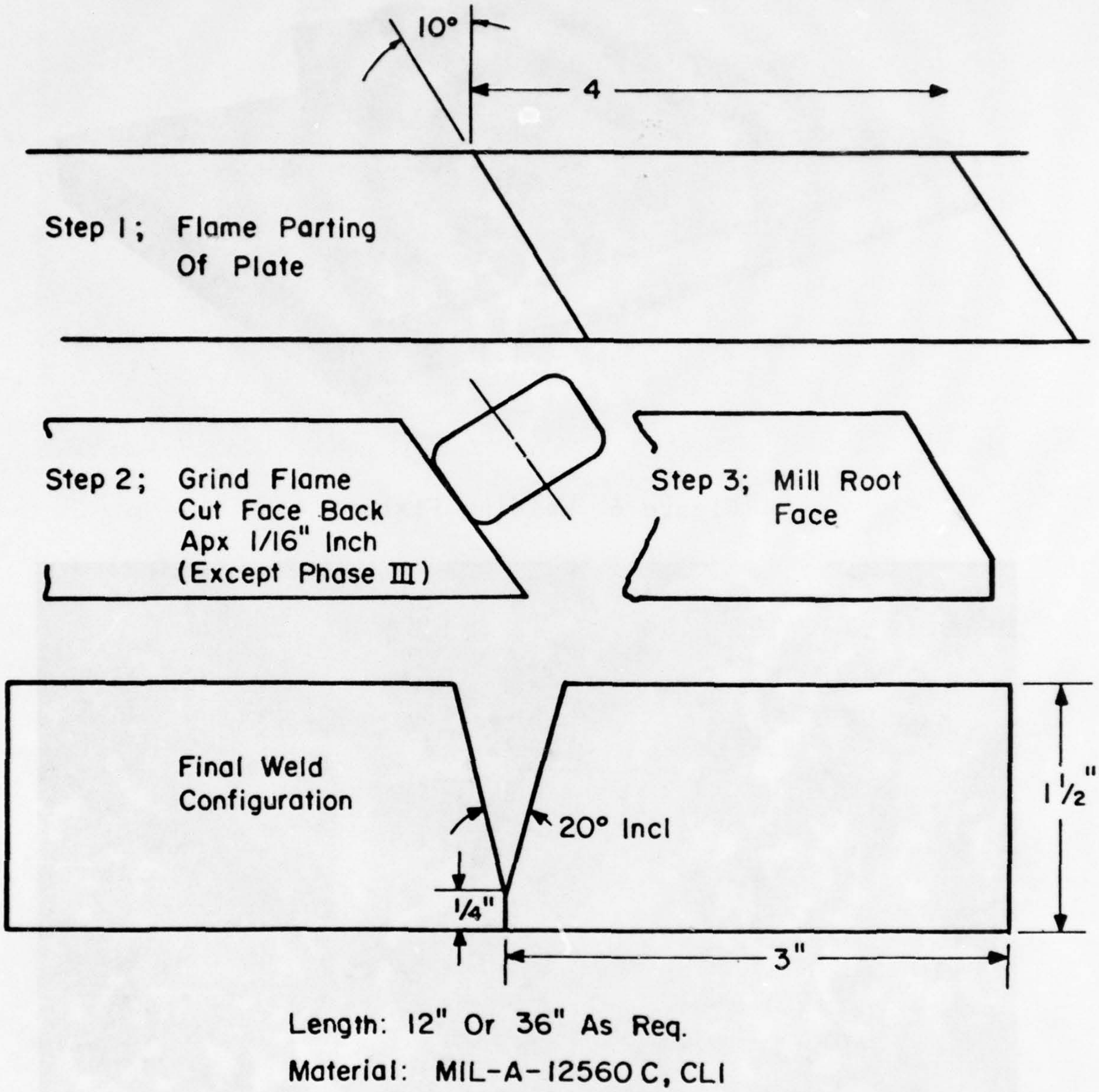


Figure 5 Specimen Preparation

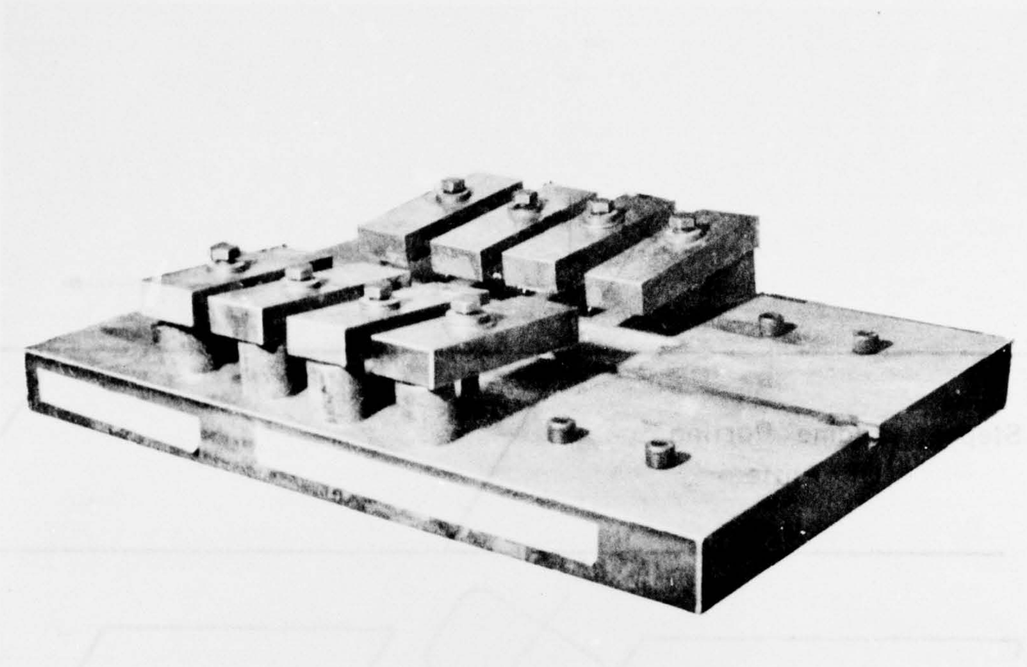


Figure 6 Welding Fixture

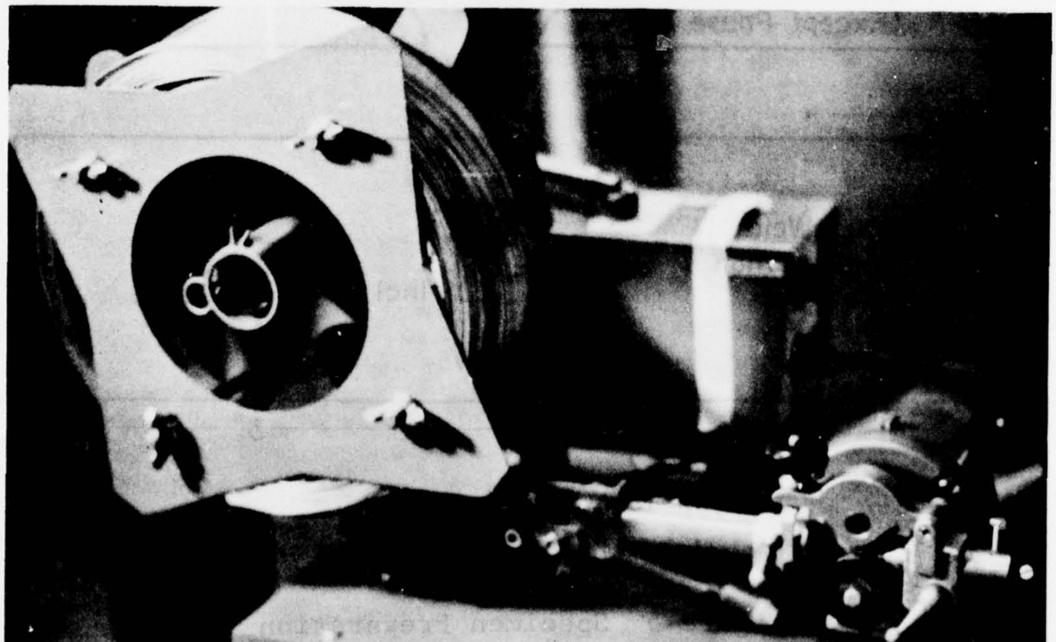


Figure 7 Wire Feeder

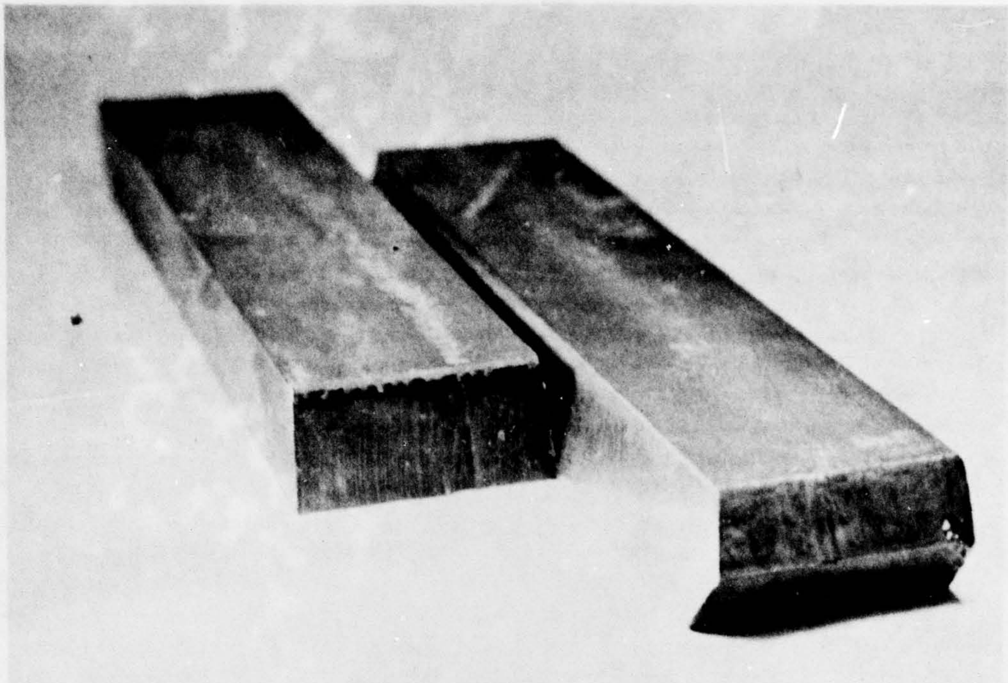


Figure 8 Prepared Specimen

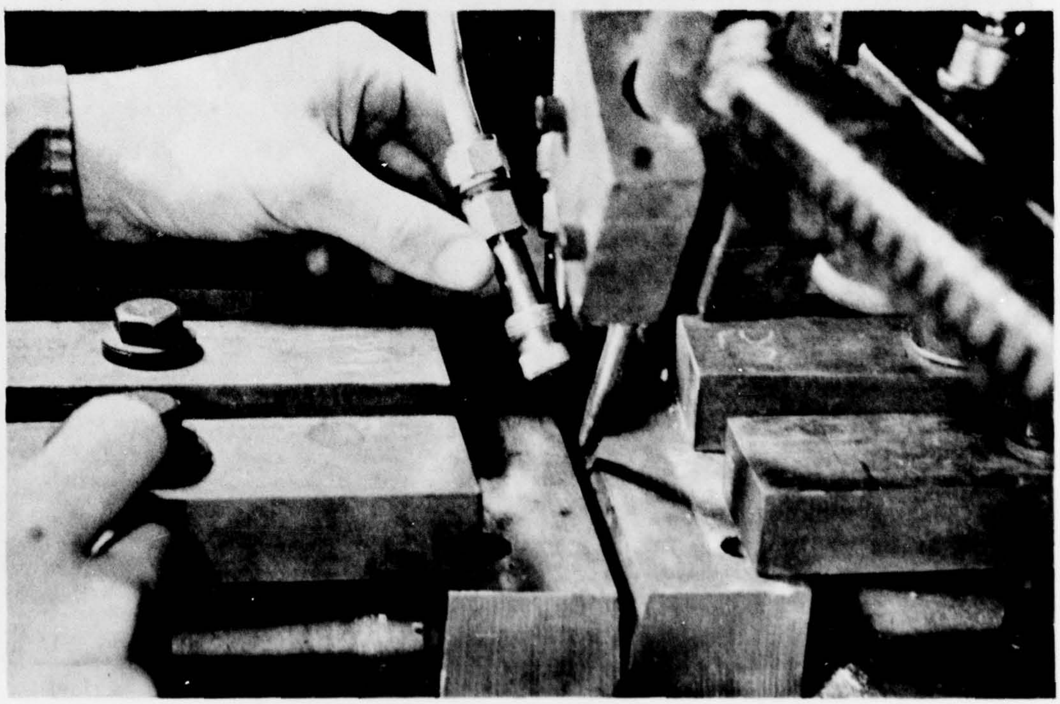


Figure 9 Setting Up the Third Bead In A 12 Bead Process

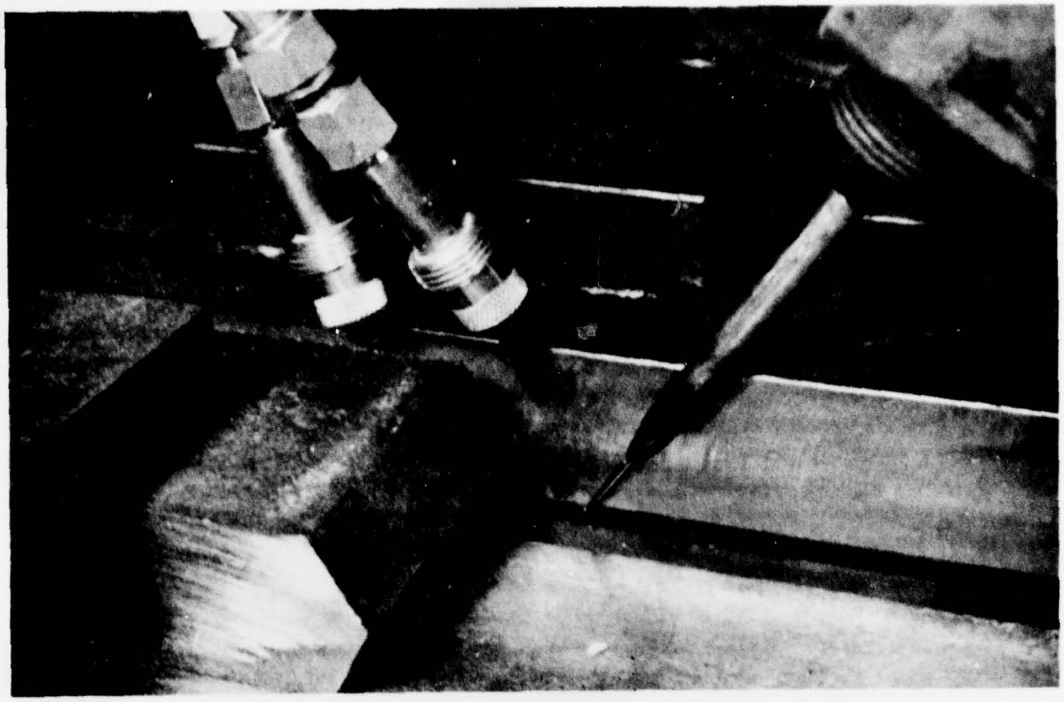


Figure 10 Arrangement of Wire

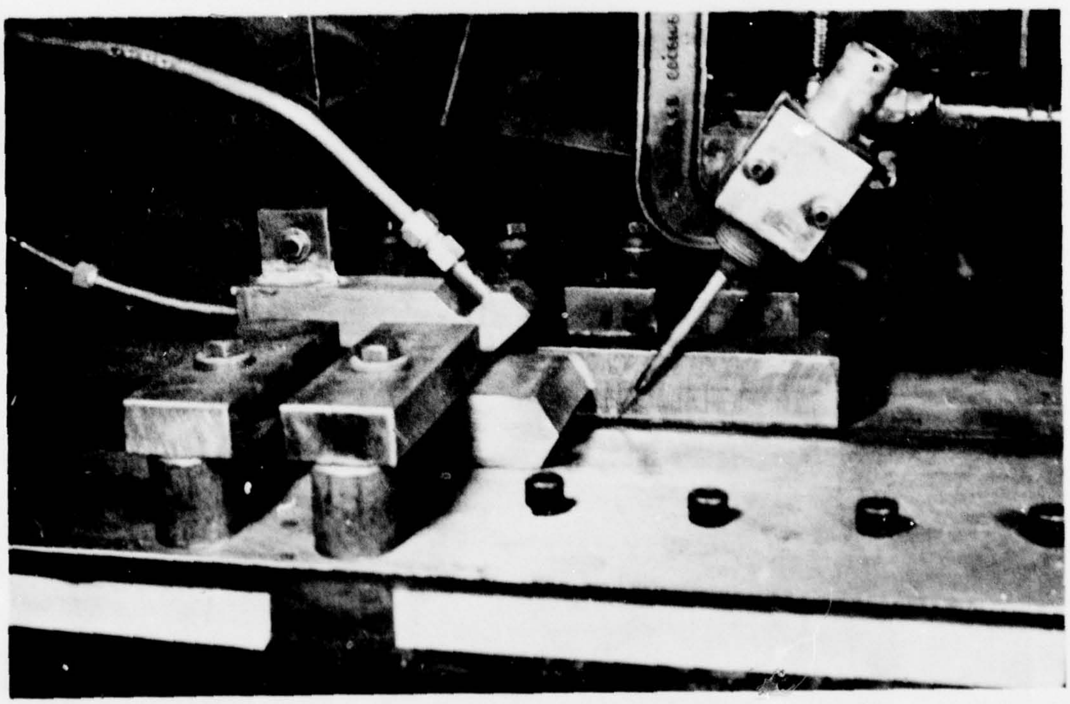


Figure 11 Jet Trailer Hood

Table 1

EXPERIMENTAL PROCEDURE SUMMARY

Basic Process: 1 1/2 in. Thick, Narrow 20° V
(1/4 in. Root); 12 kW, 1/16 in. diameter A632
Wire Feed (55°), F/7 (Coaxial) Telescope.

Joint Number	Pass* Sequence	Number of Passes	Preheat °F	Wire Feed (ipm)	Welding Speed (ipm)	He Shielding (CFH) Front Jet	He Shielding (CFH) Rear	He Shielding (CFH) Trailer	COMMENTS
101	A: Root	1	No	60	15	200	-	-	INITIAL SET-UP JOINT
	B-E: Span	4	No	120	15	200	-	-	(not to be evaluated in
	F-N: Side	9	No	120	15	150	-	-	Task 5)
		14							
102	A: Root	1	No	60	15	200	-	-	SECOND SET-UP JOINT
	B-C: Span	2	No	120	15	200 (A-L)	-	-	Greater fill in Pass A
	D-M: Side	10	No	120	15	150 (L-M)	-	-	External evaluation only
		13							
103	A: Root	1	No	60	15	200	200	-	REFERENCE JOINT-SHIELDING
	B-D: Span	3	No	120	15	200	200	-	Added second off-axis jet
	E-M: Side	9	No	120	15	300 (H)	300	-	to improve coverage of
		13							cooling weld metal
104	A: Root	1	No	60	15	100	50	-	REFERENCE JOINT-IP BRUSHING
	B-D: Span	3	No	120	15	100	50	-	Also added contact tube to
	E-N: Side	10	No	120	15	100	50	-	support wire

*Interpass cleaning by brushing on weld applied to Weld No. 104 only. Other welds adequately protected by inert gas. No evidence of silicates on surface.

Table 1 (cont.)

Joint Number	Pass* (Sequence)	Number of Passes	Preheat °F	Wire Feed (ipm)	Welding Speed (ipm)	He Shielding (CFH) Front jet	Rear	Trailer	COMMENTS
105	A: Root	1	No	60	10	100	-	50	REFERENCE JOINT-REDUCED SPEED
	B-D: Span	3	No	120	10	100	-	50	
	E-N: Side	10	No	120	10	100	-	50	
		14							
106	A: Root	1	No	120	10	100	-	50	THIRD SET-UP JOINT
	B: Repair	1	No	120	20	100	-	50	
	C-D: Span	2	No	120	10	100	-	50	
	E-F: Side(Slow)	2	No	120	10	100	-	50	
	G-N: Side(Fast)	8	No	120	20	100	-	50	
		14							
107	A: Root	1	No	120	20	200	-	100	REFERENCE JOINT: INCREASED SPEED
	B-C: Span	2	No	120	20	200	-	100	
	D-O: Side	12	No	120	20	200	-	100	
		15							
108	A: Root	1	500	60	15	200	-	150	REFERENCE JOINT-PREHEAT
	B-D: Span	3	500	120	15	200	-	150	
	E-K: Side(Med)	7	500	120	15	200	-	150	
	L-M: Side(Fast)	2	500	120	20	200	-	150	
		14							
109	A: Root	1	No	75	15	200	-	150	REFERENCE JOINT-LOW CARBON FILLER (Commercial-0.078 in. dia)
	B-D: Span	3	No	75	15	200	-	150	
	E-N: Side	10	No	75	15	200	-	150	
		14							

A. Beam Characteristics

1. Power: 12 kW (no slope used in these tests)
2. Type: High intensity (crescent) configuration
3. Oscillation: Not applicable
4. Beam Size: F/7 telescope (approx. 0.042 in. dia)

B. Filler Metal

1. Form: 1/16 in. dia wire
2. Chemistry: MIL-E-19822 Ty B88 (Airco A632)

C. Joint

1. Design: 1 1/2 in. thick 20° V with 1/4 in. root
2. Fit Up: Machined specimen (tight to 0.015 in. gap typical)
3. Cleaning: Machined surfaces

   a. Precleaning: Acetone
   b. Interpass Cleaning: Variable--See Table 1

D. Pass Sequence and Number of Passes

1. Pass Sequence: Consists of a root pass, one-to-three single-pass layers (termed "span" passes for brevity) and multipass layers made up of two side-by-side passes (termed simply "side" passes). Figure 12 illustrates the components of a sequence. Optimized capping passes will be added later in the program.
2. Number of Passes: Variable--See Table 1

E. Preheat: Variable--See Table 1

F. Welding Speed: Variable--See Table 1

G. Work Distance: Focal point where wire intersects beam 24 1/4 in. from downhand mirror. Wire focus intersection placed on top of root pass portion of weld or preceding beam as applicable.

H. Shielding: Variable--See Table 1

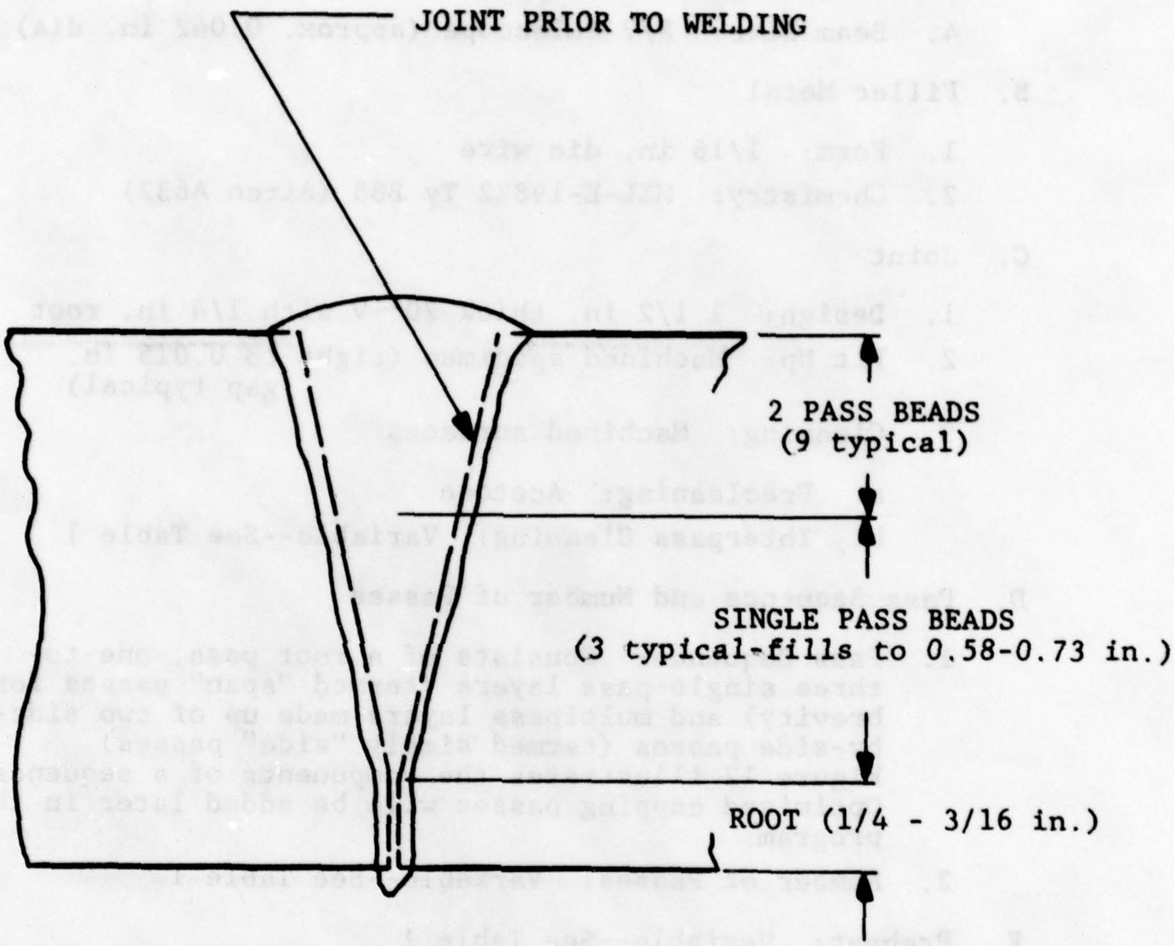


Figure 12 Typical Sequence

Nine test joints were prepared using this basic procedure. Three were for set-up purposes, and six were considered as representing a procedure variable. As a guide of the experiments, some preliminary evaluation of the cross-sections was carved out because several beads showed external evidence of cracking. The following paragraphs describe the observations made during the welding of the nine test joints.

Joint No. 101, Initial Set-Up Joint

The A632 wire proved to be somewhat more difficult to feed than the commercial wires and a wire straightener stage was employed ahead of the drive rolls. Control over wire position improved.

Joint No. 102, Second Set-Up Joint

The wire was repositioned to produce coincidence of the focal point, wire, and work surface. In this case side-wall fusion was very good throughout all fourteen passes; cracking was observed externally. A preliminary section suggested hot tearing. In this weld and each subsequent run the plate remained flat on the fixture, as would be the case with maximum restraint in an actual application.

Joint No. 103, Reference Joint--Shielding

Series 103 was run with two helium gas shields, each operating at 200 cfh. This was essentially twice the helium flow of two previous series. A preliminary cross-section revealed excellent soundness in the upper portion of the weld and fewer large tears, but more small ones compared to No. 102. Micrographs of this section revealed intergranular tearing or incipient melting in addition to the macro tearing. Side wall fusion was excellent.

Joint No. 104, Reference Joint--Interpass (IP) Brushing

Continuing to use the two-jet arrangement, but at lower flow rates (150 & 50), series 104 explored interpass cleaning in the form of wire brushing. The results of this series were

essentially the same as those of No. 103; cracks were smaller but tears appeared more numerous.

Joint No. 105, Reference Joint--Reduced Speed

A 33 percent reduction in travel speed was made. The much larger weld beads resulting from this lower speed showed a greater tendency to wet one side-wall or another. This tendency made it impossible to control the position of the deposited metal, and the deposition of subsequent passes was difficult. In any event the tears were still present, emanating from a large centerbead crack.

Joint No. 106, Third Set-Up Joint

This series became a test bed for the number of ideas, the first of which was the question of repair on a seriously disrupted bead. The root pass had been attempted at a filler bead wire feed rate. The added metal caused the bed to fall out of the joint. Welding continued at 20 ipm, twice the originally intended travel speed. The root pass situation appears to have been successfully repaired at least to the extent that there are no defects other than the internal cracks which were observed in other welds.

Joint No. 107, Reference Joint--Increase Speed

All welding was performed at 20 ipm travel speed (5 ipm faster than initial welds). Additionally, a "jet-trailer" hood shield (Fig. 11) was used. This hood proved easier to position and definitely reduced the amount of oxidation present after each pass. These smaller beads, produced by the high speed, were not well suited for the weld joint in terms of subsequent deposition. The tendency for internal cracking remained about the same.

External observations during Task 4, Adaptation of the Procedure to Armor, suggest that the process behaves differently in armor than in commercial practice.

Preliminary sections through the welds suggest three types of indications:

a. Porosity: Very slight and scattered. Estimated to meet any radiographic standard.

b. Voids: Irregularly shaped, with regular walls, suggesting pockets formed by bridging of metal. The bridging action is probably caused because the stiff A632 wire does not have the feedability of the lower strength commercial wires (typically AWS A5.18) and tends to weave in the groove.

c. Cracks: Apparently hot tears. There are two distinct orientations--horizontal (short and parallel to the plate surface) and vertical.

In order to determine which of several factors is influencing the above-mentioned cracking, a number of procedural adjustments will be employed during the continuation of Task 4 during the next reporting period. These adjustments include:

1. Reduction of interpass temperatures to ambient throughout the entire sequence.
2. Modification of the energy distribution within the F/7 (0.042 in.) spot.
3. Modify wire feed technique to emphasize shallower beads and/or less wall erosion.
4. Introduce a large spot (0.110 in.).
5. Introduce large wires.

NOTE: Items 4 & 5 were to be evaluated in Phase II, but will be attempted in this task to determine their effect on weld soundness.

4. PROPOSED PROGRAM FOR THE NEXT REPORTING PERIOD (1 January 1979 through 31 March 1979)

4.1 Task 5 - Evaluation of the Process

Sections from the welds produced thus far in Task 4 will be subjected to:

1. Macro and micro examination of ground and etched sections to determine the nature and source of deficiencies in weld quality.

2. Tensile tests to determine ultimate strength and elongation (in appropriate material).

3. Charpy tests at 20° F to determine energy absorption (in appropriate material).

4.2 Task 6 - Data Collection

Work under this task will include the collection of data and the effect on trends caused by process parameter changes. The types of data to be collected include, but are not limited to:

1. Comparison of observed mechanical properties with references

2. Comparison of soundness with references

3. Recorded rate and cost of completed weld for 1 1/2 in. joint

4. Description of an evolved 12 kW process

5. Tabulation of specific settings for evaluated welds and resultant trends

6. Welding problems encountered during the production of welds and their solutions.

In summary, the program is on schedule and the effort in the next period will emphasize elimination of cracking.

Appendix 1

SUMMARY OF CHARACTERISTICS OF IITRI LASER FACILITY

Characteristic	Specification
Type	Closed cycle gas laser with electron beam ionizer.
Operating Mode	Continuous wave output, steady-state operation; manual, automatic and jog capabilities built-in.
Output Power	Continuously adjustable over the range of 1 kilowatt to 15 kilowatts with closed-loop power control and direct-reading power monitor.
Output Power Stability	± 3% of set-point; 1/4 second response time.
Construction	Complies with Joint Industrial Council and National Electrical Manufacturer's Association Standards. Complies with U. S. Government standards for noise level and x-radiation.
Optics	All optical surfaces are reflecting.
Output Window	Aerodynamic window.
Output Beam	Approximately f/25 diverging beam beyond aerodynamic window.
Mode Structure	Radially symmetrical focal spot with approximately Gaussian distribution about center of spot.
Spot Size	Approximately 0.006 times the f-number of a telescope used to generate the spot.

United States Steel Corporation

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F. D. SEAMAN

CENTRAL STEEL DIVISION

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312/329-2000

November 10, 1978

IIT RESEARCH INSTITUTE
10 W 35th St.
Chicago, Illinois 60616

Attention: Dr. Breyer

SUBJECT: Your Order 75543
Stock Armor Plates

Dear Dr. Breyer:

The following is the information you have requested for the subject plates:

Specification:	MIL-A-12560C, Class I
Plate No.:	0153660 (Parent Plate)
Heat No.:	71D422

Plate Size: 39.4' x 78.8" x 1.54"

Chemistry (Ladle Analysis)

C	M	P	S	SI	MO	AL	B
.26	1.43	.008	.010	.25	.50	.043	.003

	Plate Hardness #1 End	#2 End
Top Surface	321 BHN	302 BHN
Bottom Surface	302 BHN	302 BHN

Ballistic Qualification Plate for Lot:

Plate No.-0152031A
Cross Section Hardness - 321 BHN
Transverse CVN Impact (-40 Degrees F) - 63, 70 Ft. -Lbs.

United States Steel Corporation
CENTRAL STEEL DIVISION

Dr. Breyer November 10, 1978

Stock Armor Plate

Ballistic Firing Record - AR 35312, Excess Factor + 181
37 MMAP: 0 Degrees Obliquity

If you have any questions, please feel free to call.

Sincerely,

UNITED STATES STEEL CORPORATION

R F Marovich

Service Representative
Chicago District Sales

RFM/pmd